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Estimating the Weight of Douglas-Fir Tree Boles and Logs With an Iterative Computer Model

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Abstract

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A computer model that estimates the green weights of standing trees was developed and validated for old-growth Douglas-fir. The model calculates the green weight for the entire bole, for the bole to any merchantable top, and for any log length within the bole. The model was validated by estimating the bias and accuracy of an independent subsample selected from the original stand. Calculated weights were compared to actual weights as measured on truck scales. The model accurately estimated the weight of logs (less than 10 percent error) and provides an estimation technique that is expected to have application for various elements of timber management.

Keywords: Models, weight scaling (log), log weights, computer programs/programing.

Summary

The accurate estimation of bole weights in standing trees is valuable information in the planning of timber harvesting operations, particularly aerial logging. The economic viability of "heavy-lift" aerial logging, such as Heli-Stat, Cyclo-Crane, helicopters, and cable systems, will be partially dependent on accurate estimates of the payloads. We developed an iterative computer model for old-growth Douglas-fir that combines various prediction algorithms for taper and green density. Green weight can be estimated for various log lengths and merchantable top limits.

The data were collected in the Mount Hood National Forest in northwest Oregon. The model was validated with independent data by comparing predicted weights with weights measured on truck scales. Statistics on bias and accuracy are presented.

Results demonstrated acceptable error (less than 10 percent) in estimating log weights. The model analyzes the potential wood products from a stand under various logging constraints—specifically, the product characteristics (length and diameters of logs) and the weight capacity of the yarder. An example of the computer program, written in BASIC (programming language), is available from the authors.

Contents

Introduction

There has been an increased demand in the 1980's for mathematical models that can accurately estimate the weight of logs, boles, whole trees, and forest stands. The demand has grown because of the increase in the variety of forest products and the greater use of weight scaling, and because of the critical need for accurate weight estimates in various logging systems, especially aerial logging. A maximum payload with a minimal chance of an overload is essential in aerial logging because of the high operating costs. Logs must also be bucked to maximize grade and length requirements of the mill. The purpose of this study was to develop and validate a weight prediction model for standing Douglas-fir trees (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) that could be used in planning for "heavy-lift" aerial logging. Heavy-lift is a term used to describe aerial yarders with capacities for large loads, such as the Sikorsky (S-64) Skycrane helicopter and the proposed Heli-Stat and Cyclo-Crane airships.[1] The model also has application in other areas of forestry where estimates of tree bole, log, and crown weights are needed.

A common method of estimating the weights of trees is to develop an empirical relationship (regression equation) between weight as the dependent variable and diameter outside bark at breast height (DBHob) and tree height as the independent variables. There are two problems with this approach: (1) the model is limited to a single output, such as weight of the bole or the weight of a single log; and (2) the data used to develop the regression equations are difficult to collect. The collection of data is difficult because the harvest units may contain large timber and the units are often in remote areas. Costly equipment is needed to lift the boles, and the equipment is difficult to move to the sites. Also, a separate regression equation is required for each log length and for each merchantable top limit.

An alternative technique is to not weigh the boles but to calculate the weights from systematic measurements of diameter, bark thickness, and green density (Waddell and others 1984). These measurements provide the data necessary to develop prediction equations for taper (or volume) and green density. The green weight is computed from the product of the volume and green density predictions. This type of model can be constructed, with the aid of a computer program, to produce estimates of weights for any size bole with variable log lengths and merchantable top limits. Refer to Burkhart (1977), Cao and others (1980), Demaerschalk and Kozak (1977), and Max and Burkhart (1976) for discussions on the computational procedures and on the accuracy of various bole volume and taper equations.

The objectives of this study were (1) to develop a model for Douglas-fir trees that would estimate weights for the entire bole, for the bole to various merchantability limits, and for logs with various lengths; and (2) to evaluate the accuracy of the model by comparing estimated weights with actual weights from an independent subsample from the same area (harvest unit).

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[1] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Methods

Study Area

The study area was in the Clackamas Ranger District, Mount Hood National Forest, in northwest Oregon. The area was 14 acres and contained only old-growth Douglas-fir. The 280-year-old stand was partially cut in 1973 as a shelterwood silviculture treatment.[2]

Sampling

All trees within the area were measured for DBHob[3] with a diameter tape and total height[4] with a clinometer. A total of 185 trees were tagged and assigned a sequential number. The DBHob measurements were entered into a computer and were sorted into four diameter classes (11-20 inches, 21-30 inches, 31-40 inches, and greater than 41 inches). A stratified random selection of 18 sample trees was made by proportionally allocating the number of samples for each diameter class based on the number of trees contained (population stratum) in each class (Freese 1962).

Measuring Sample Trees

The 18 sample trees were felled and each tree was measured for total height. The diameter of the butt end of the bole was measured by averaging the longest and shortest diameter (to the nearest 0.1 inch) for both inside and outside bark. The bole was then marked at 3-foot intervals up to a 6-inch top (diameter outside bark (dob)). At every 3-foot interval, the dob was measured with calipers. Bark thickness was also measured with a bark thickness gauge in three perpendicular locations around the circumference of the bole. At every 6-foot interval, starting at 3 feet from the base of the bole, three increment cores were extracted from the wood (perpendicular locations). The green density of each core was measured with a Bergstrom xylodensimeter (Waddell and others 1984), and the mean of the three green densities was calculated. This resulted in one green density value for every 6-feet of tree bole. Figure 1 illustrates how the data were collected from each sample tree.

Weighing Validation Logs

About one-half of the population trees (93) were felled and bucked into various log lengths. Each log length was measured, and the log was tagged for identification. The logs were then yarded (using horses) to a landing and weighed with a self-loading log truck and platform scales. A total of 326 logs were weighed.

[2]The stand was selectively harvested in 1973 and then underburned to control competing vegetation.

[3]Diameter outside bark is measured at 4½ feet on the uphill side of the tree.

[4]Total height is measured to the tip of the crown.

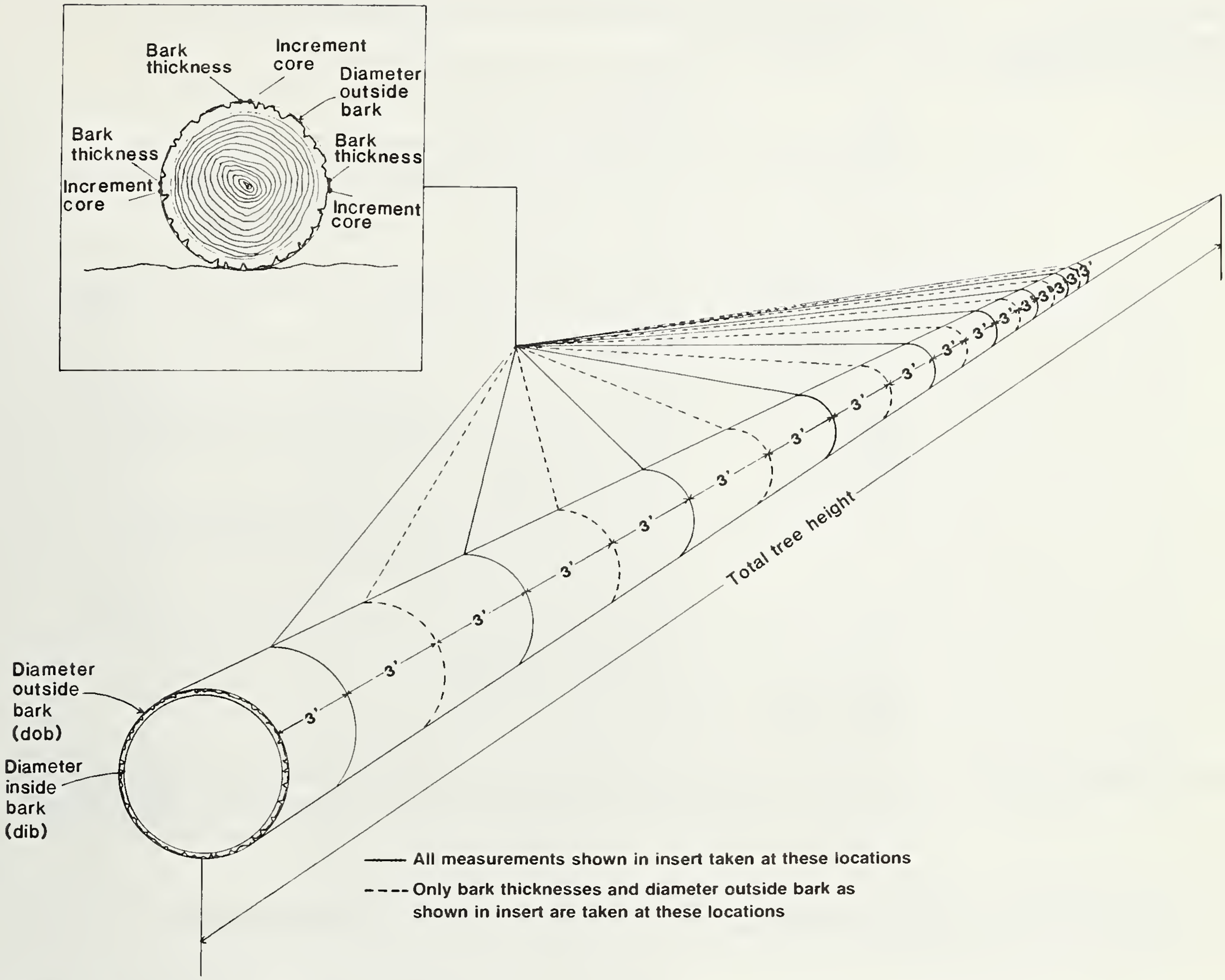

Figure 1—The type and location of information collected from the boles of each sample tree.

Analysis and Description of the Computer Model

Notation

The following is a list of variables used in the predictive equations and in the computer program.

a, b_i	= regression coefficients estimated from sample data.
ob, ib	= outside or inside bark.
DBHob, DBHib	= diameter in inches at 4½ feet.
Rob, Rib	= diameter ratios (dob÷DBHob and dib÷DBHib, both as functions of relative height in the bole).
relht	= relative height (height at a selected position in the bole÷total height).
Doble, Dible	= diameter outside and inside bark in inches at the large end of the bole segment.
Dobse, Dibse	= diameter in inches at the small end of the bole segment.
ds(ob), ds(ib)	= diameter in inches at the end of the bole (stump cut).
gden	= density of the green wood (pounds per cubic foot).
brkden	= density of the green bark (pounds per cubic foot).
Vob, Vib	= volume (cubic feet).
C	= pi÷(4x144); a constant that, when multiplied by the diameter in inches, results in the basal area of the cross-sectional area (square feet).
L	= length of a log.
lseg	= iteration or segment length for computing volume and weight (computer program).
totht	= total height of the tree.
MT	= merchantable top limit.

Model Development

The iterative computer model combines a calculated volume with a predicted green density for small segments of the tree bole; the model begins at the base and ends at the top of the bole. This is accomplished with six types of equations or algorithms:

Type A. Equation for predicting the inside bark diameter at DBH:

$$\text{DBHib} = a + b(\text{DBHob}) .$$

Type B. Taper equations for predicting bole diameters at various heights:

$$\text{Rob and Rib} = a + b_1(\text{relht}) + b_2(\text{relht})^2 + b_3(\text{relht})^3 + b_4(\text{relht})^4 + b_5(\text{relht})^5 .$$

Type C. Taper equations for predicting diameters at the end of the butt log:

$$\text{ds(ob)} = a + b(\text{DBHob}), \text{ and } \text{ds(ib)} = a + b(\text{DBHib}) .$$

Type D. Smalian's volume formula:

$$\text{Vob} = \text{CL}(\text{Dob}^2 + \text{dob}^2)/2 \text{ , and}$$
$$\text{Vib} = \text{CL}(\text{Dib}^2 + \text{dib}^2)/2 .$$

Type E. Butt log formula (Bruce 1982):

$$Vob = CL(0.25(ds(ob))^2 + 0.75(DBHob)^2) \text{ , and } Vib = CL(0.25(ds(ib))^2 + 0.75(DBHib)^2)$$

Type F. Equation for predicting the green density of the wood:

$$gden = a + b_1(relht) + b_2(relht)^2 + b_3(relht)^3 \text{ .}$$

Linear regression techniques were employed to fit predictive equations (A, B, C, and F) to the measurements taken on the sample trees. Type A equations convert the measured DBHob to a predicted DBHib. Type B equations are taper equations that describe the profile of the tree (ob and ib) (fig. 2). We elected to use a taper equation and to calculate the volume iteratively within a computer program rather than use a volume ratio or direct integration of volume. The former approach uses "user interactive inputs" that produce for each standing tree a greater diversity of output, such as diameter, volume, and weight, for a variety of log lengths and merchantable top diameters. Both type B equations were conditioned such that when the relative height equals zero, the diameter ratio (Rob and Rib) is one, and when the relative height equals one, the diameter ratio is zero (Demaerschalk and Kozak 1977). Relative height for the diameter ratios begins at DBHob. Type C equations predict the diameters at the end of the bole (stump cut) from DBH. Type D equations are from Smalian's volume formula (Dilworth 1981), which was combined with the type B equations to provide estimates of volume for segments of the bole above DBH (ob and ib). The type E equations are from Bruce's butt log volume formula (Bruce 1982), which was combined with type C equations to provide estimates of volume for the lower bole (below DBH, ob and ib). Type F equations predict the density of green wood for various increments of relative height (fig. 3). Relative height begins at the stump in the equation for predicting green density .

There are two different relative heights computed for a given bole segment (relht1 for green density starting at the stump and relht2 for diameter ratio functions starting at DBH). Each relative height is calculated differently within the iterative process so that the functional solutions for green density and diameter ratio are matched with the appropriate bole segment.

A computer program was created to read the stand variables (input), to organize the calculations (processing) that determine bole dimensions (such as diameter, volume, density, and weight) from the equations discussed previously, to create loops to increment the calculations, and to provide mechanisms for the storage and output of summary information. The program was developed in sections called subroutines.

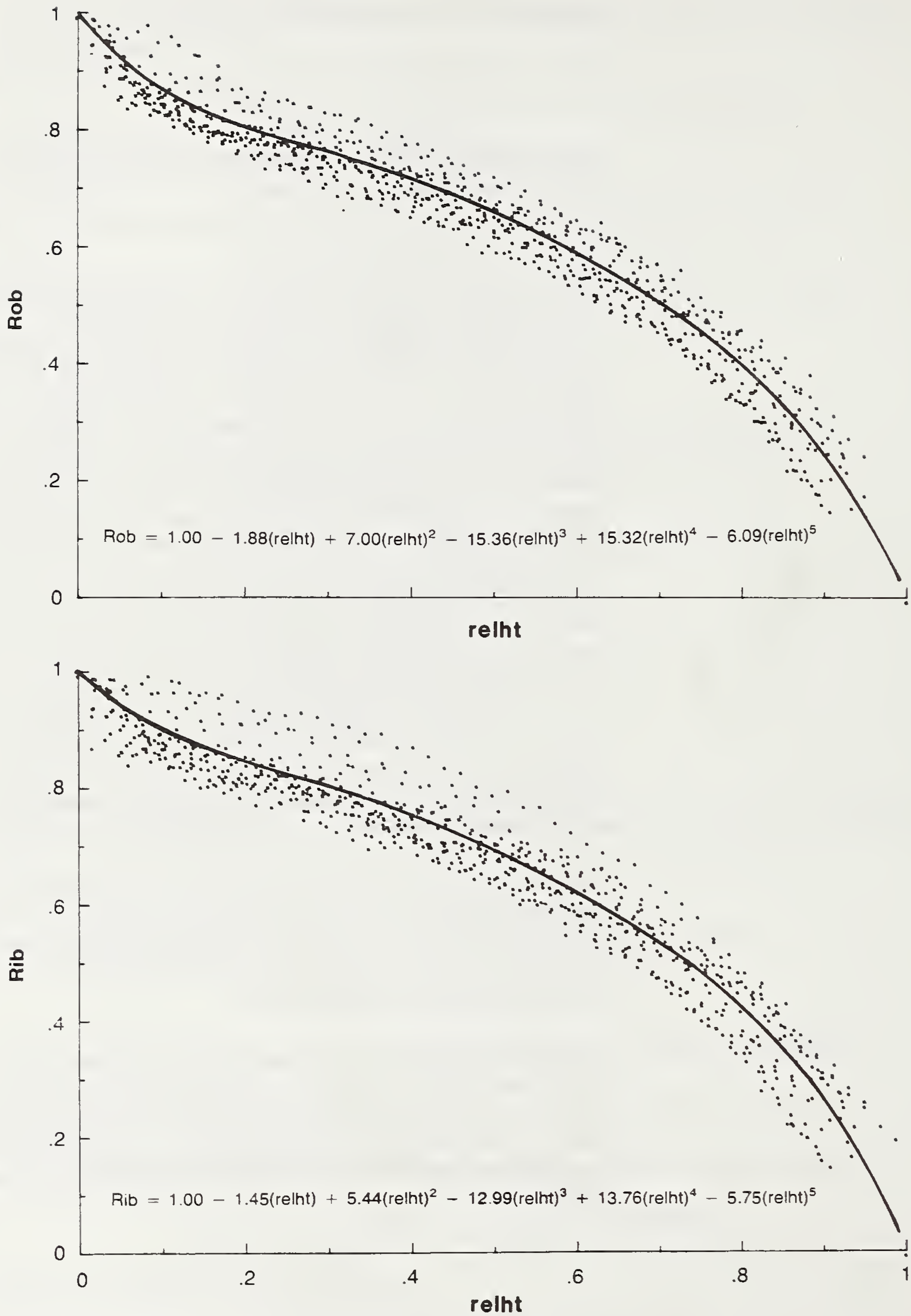

Figure 2—Equations for predicting the outside and inside bark diameters from relative height. Rob and Rib are the diameter ratios for outside and inside bark respectively; relht is the relative height

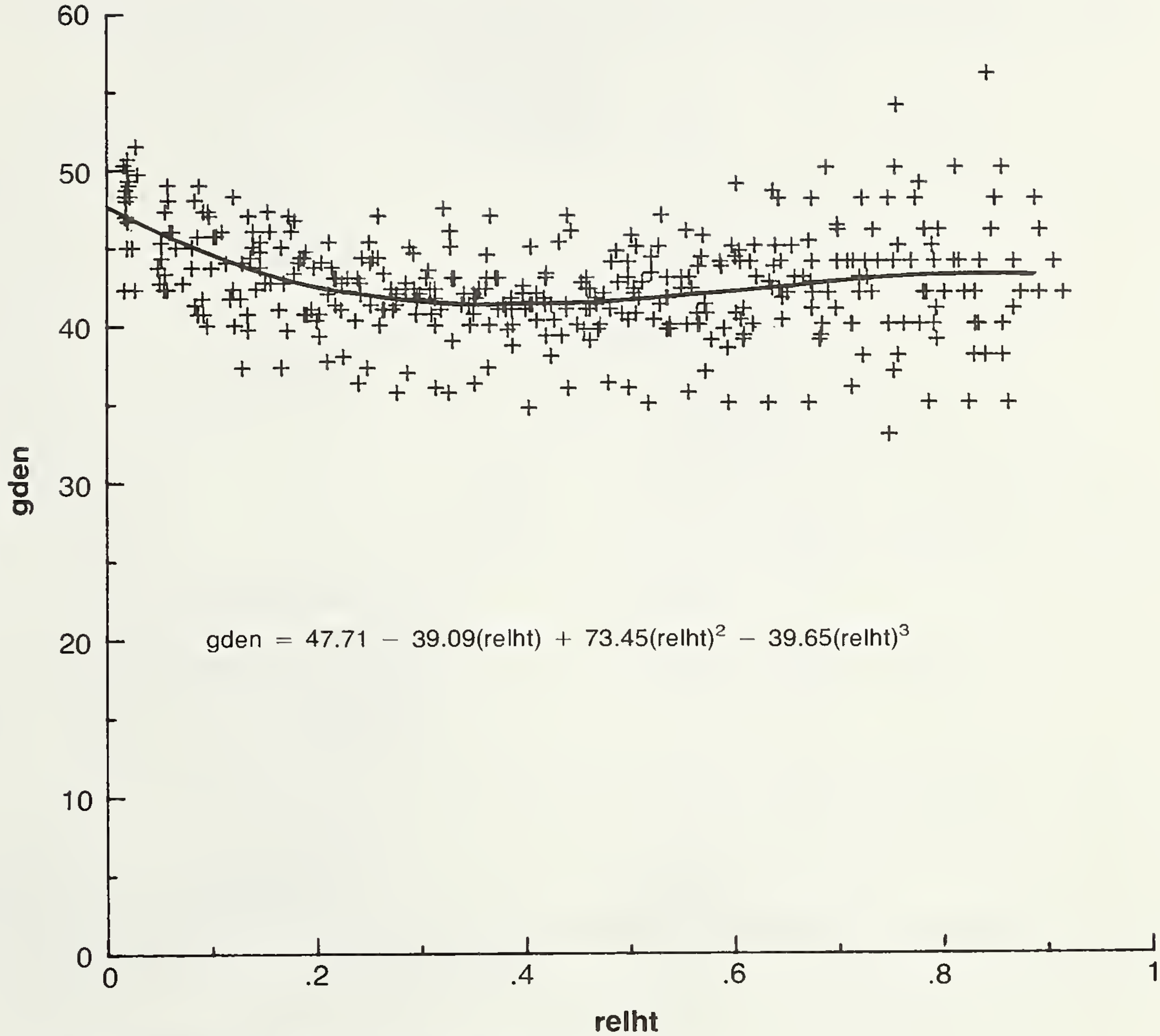

Figure 3—Equation for predicting the green density of wood. Gden is green density measured with the Bergstrom xylodensimeter, and relht is the relative height.

Subroutine that calculates the weight of the bole—Stand inventory data in the form of a species code, DBHob, and total height measurements are entered into a file. The file is then read by the iterative program. Stump height, bark density, and the number of iterations are entered by the user in response to prompts in the program (fig. 4). The subroutine begins by calculating the weight of the bole segment from the stump to DBHob (process one). This is accomplished by combining equations (A), (C), (E), and (F) (table 1).

The bole of the tree above DBHob is then divided into many small segments (iterations), and calculations of each segment's weight take place using equations (A), (B), (D), and (F) (process two) (table 2). Data arrays are created from the equations as the program moves incrementally from DBHob to the top of the tree and stores the weights, cumlative lengths, and diameters. Each tree in the data file will go through the same iterative process. The user controls the number of iterations, which dictate the size and number of segments considered for each tree. The greater the number of iterations, the smaller the bole segment, which theoretically reduces the error attributed to the calculation of volume.

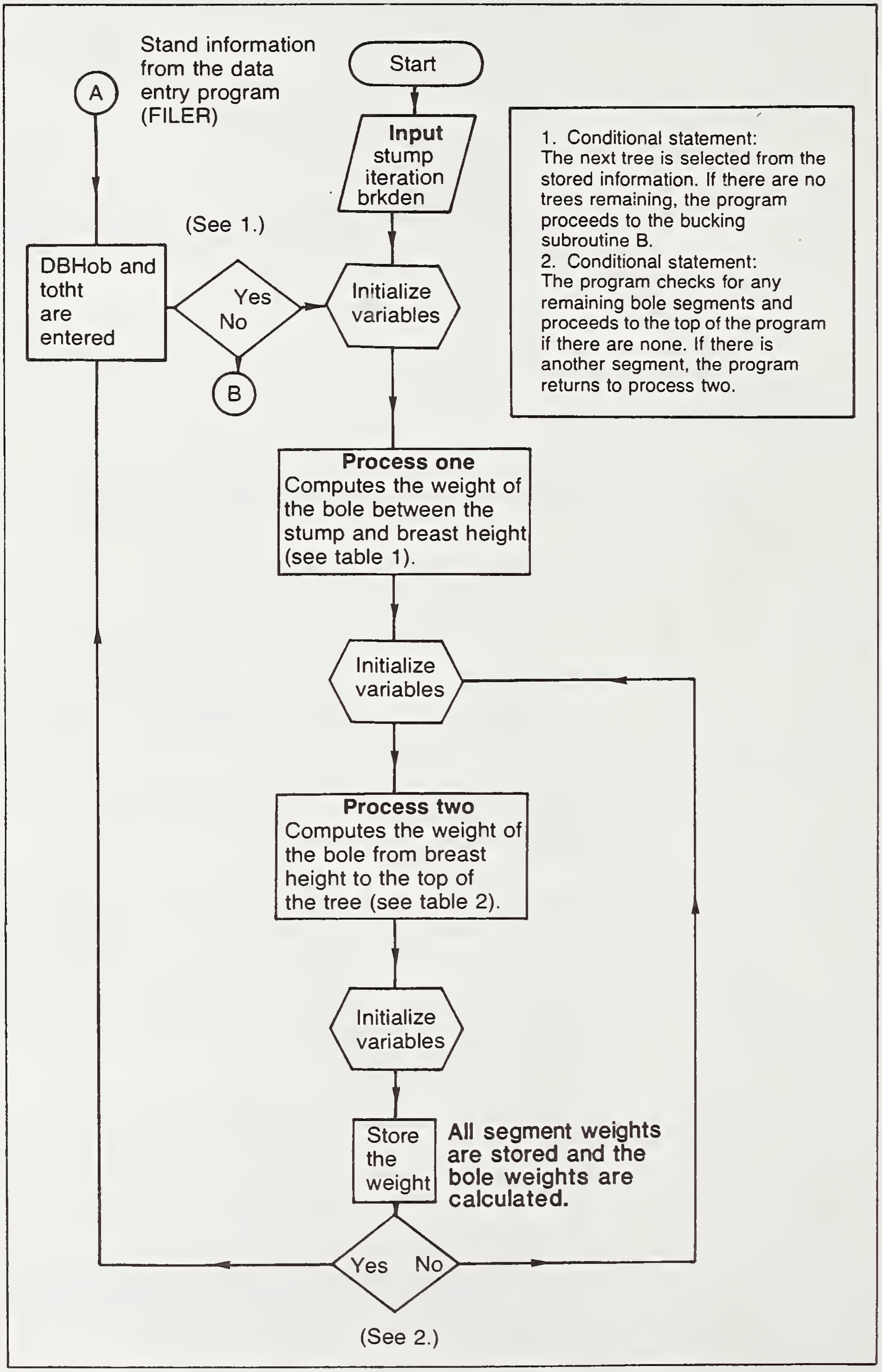

Figure 4—Flowchart of the subroutine that estimates the weight of tree boles.

Table 1—Process one: calculations required to estimate the weight of each bole from the stump to breast height

Step number	Criterion variable	Input variable 1/	Algorithm
1	[DBHib]	DBHob	$a+b_1(\text{DBHob})$
2	[ds(ob)]	DBHob	$a+b_1(\text{DBHob})$
3	[ds(ib)]	[[DBHib]]	$a+b_1(\text{DBHib})$
4	[relht1]	stump, totht	$(4.5-\text{stump})\div(\text{totht}-\text{stump})$
5	[gden]	[[relht1]]	$a+b_1(\text{relht1})+b_2(\text{relht1})^2+b_3(\text{relht1})^3$
6	[Vob]	DBHob, dsob, stump	$(C)(4.5-\text{stump})(0.25\ (\text{ds(ob)})^2+0.75\ (\text{DBHob})^2)$
7	[Vib]	[[DBHib, ds(ib)]], stump	$(C)(4.5-\text{stump})(0.25\ (\text{ds(ib)})^2+0.75\ (\text{DBHib})^2)$
8	[Vbark]	[[Vib, Vob]]	Vob-Vib
9	[weight]	brkden, [[gden, Vbark, Vib]]	(Vib)(gden)+(Vbark)(brkden)

1/ Double brackets indicate that the input variables have been calculated in a previous step.

Table 2—Process two: calculations required to estimate the weight of a single bole segment above breast height

Step number	Criterion variable	Input variables 1/	Algorithm
1	[lseg]	totht, iterations	$(\text{totht}-4.5)\div(\text{iterations})$
2	[relht1]	stump, totht,[[lseg]]	$(\text{lseg}+(4.5-\text{stump})\div(\text{totht}-\text{stump}))$
3	[relht2]	stump, totht,[[lseg]]	$(\text{lseg}+(4.5-\text{stump})\div(\text{totht}-4.5))$
4	[Rob]	[[relht2]]	$a+b_1(\text{relht2})+b_2(\text{relht2})^2+b_3(\text{relht2})^3+b_4(\text{relht2})^4+b_5(\text{relht2})^5$
5	[Dobse]	DBHob, [[Rob]]	(DBHob)(Rob)
6	[Rib]	[[relht2]]	$a+b_1(\text{relht2})+b_2(\text{relht2})^2+b_3(\text{relht2})^3+b_4(\text{relht2})^4+b_5(\text{relht2})^5$
7	[Dibse]	[[DBHib, Rib]]	(DBHib)(Rib)
8	[Vib]	[[Dible, lseg, Dibse]]	$(C)(\text{lseg})((\text{Dible})^2+(\text{Dibse})^2\div 2)$
9	[Vob]	[[Doble, lseg, Dobse]]	$(C)(\text{lseg})((\text{Doble})^2+(\text{Dobse})^2\div 2)$
10	[Vbark]	[[Vob, Vib]]	Vob-Vib
11	[Wbark]	brkden, [[Vbark]]	(Vbark)(brkden)
12	[gden]	[[relht1]]	$a+b_1(\text{relht1})+b_2(\text{relht1})^2+b_3(\text{relht1})^3$
13	[weight] 2/	[[Vib, Wbark, gden]]	(Vib)(gden)+Wbark

1/ Double brackets indicate that the input variables have been calculated in a previous step.

2/ The weights are stored in arrays by diameter class and species. The arrays are accessed by the bucking subroutine at a later stage in the program.

Subroutine that simulates the bucking of the bole—The next subroutine considers the weight, length, and diameter arrays processed previously and partitions each tree into log weights, log lengths, and log-end diameters (fig. 5). The user enters the target weight for the yarder in pounds. The target weight is a value under the absolute capacity of the yarding machine. The target will become a constraint criterion for producing long logs. Multiple runs of the program can be made using varying target weights to determine the approximate target weight that is low enough to avoid excessive stress on the equipment and to avoid "aborts" (aborts in aerial logging are loads that are to heavy to lift or must be dropped before reaching the landing). The target weight must also be high enough to allow efficient use of the yarding equipment and to produce maximum log lengths. For example, in heavy-lift aircraft, such as the Skycrane S-64 helicopter, the absolute capacity of the machine is about 20,000 pounds, but because of fuel and environmental conditions, the real capacity may fall below 16,000 pounds. A safe target might be 15,000 pounds.

The next step in the program is to enter the merchantable top diameter. Typically 4-, 6-, or 8-inch tops are considered, depending on the specifications of the timber sale. The next set of entries is the preferred bucking lengths. The program will select from three preferred lengths; the longest bucking length is the highest preference. A minimum length for the butt logs and a minimum length for all other logs (minimum merchantable log) are also entered.

The program accumulates the weights, lengths, and diameters of small sections of the bole from the base upward until either the accumulated length exceeds the longest preferred length or the weight is greater than the target weight. If the weight is greater than the target and the length is less than the preferred length, the second preferred length is bucked, and a new weight is compared to the target weight. This process continues until all trees are bucked into the appropriate lengths, and weights are predicted for each log. If the weight of the butt log is above the target weight and the length of the butt log is below the minimum length entered, the log is ripped lengthwise and each pair of new logs is compared to the target weight. Ripping logs with a falling saw is a common and expensive activity in aerial logging and often occurs when there is a combination of low lift (yarder) capacity and large timber.

All other logs falling below the third preferred length but above the minimum length are considered merchantable logs and are given a predicted weight. Materials falling below the minimum length, because of the lack of bole wood between the last log and the merchantable top, are left in the woods and are designated as "residue" in the program.

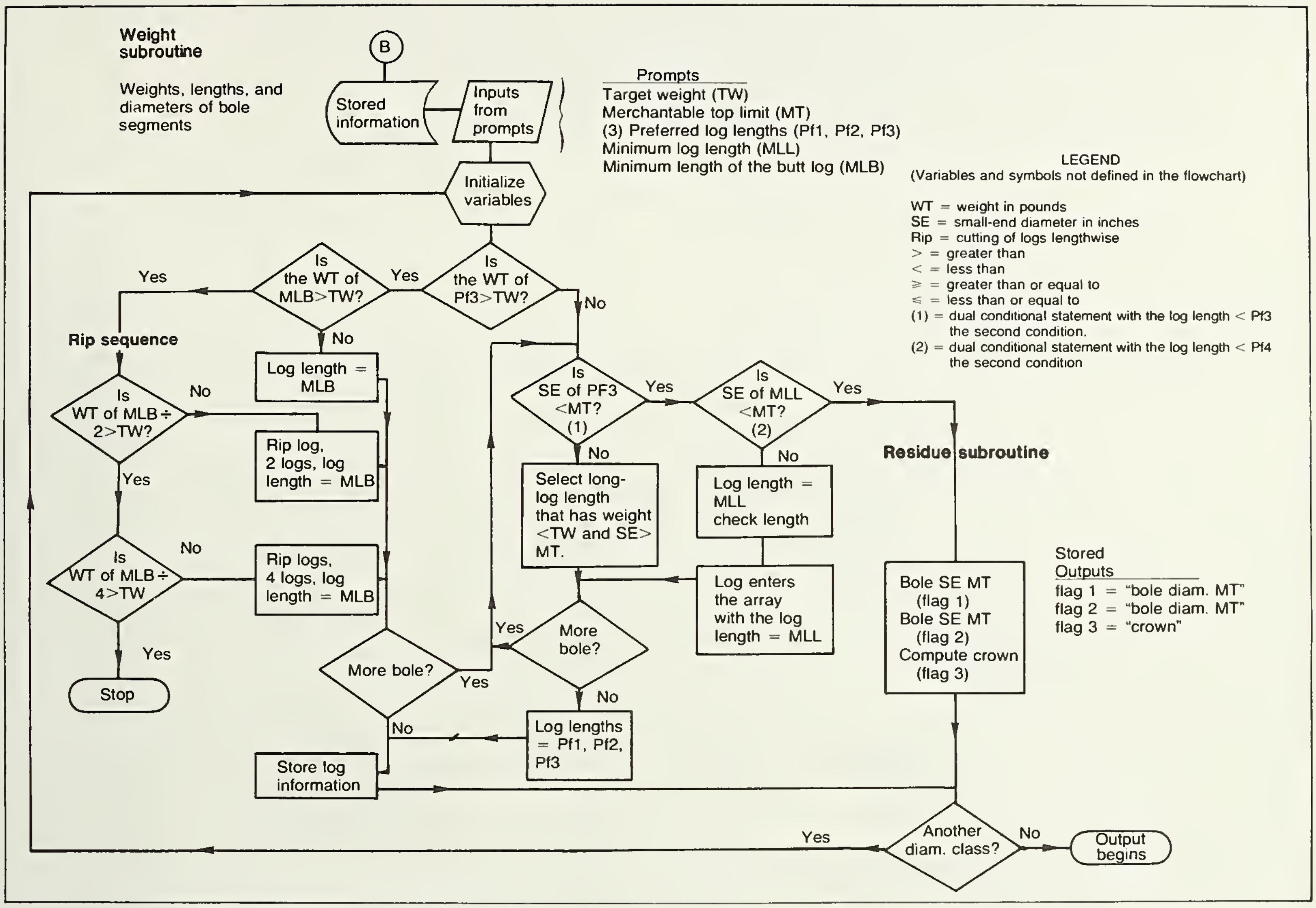

Figure 5—Flowchart of the subroutine that partitions the bole into logs.

The log weight table is produced next (fig. 6). Each tree or diameter class has a separate output that includes the number of merchantable logs, the total length of the bole used by the model, the estimated weight of the bole, and the lengths and estimated weights of the logs. The bole and log lengths printed in the table will be slightly different from the total height of the bole and preferred lengths of the logs that the user enters. This difference is the result of rounding error associated with the iterative process. The number of iterations that the user enters and the length of the bole contribute to the length that the model uses to iteratively sum the weights (segment length equals total height divided by the number of iterations). The greater the number of iterations or the shorter the bole, the closer the length in the table will be to the lengths entered by the user.

CRUISE INFORMATION FOR OLD-GROWTH DOUGLAS-FIR

DIAMETER CLASS (IN)	TOTAL HEIGHT(FT)
10	85
20	95
30	110
40	165
50	180

BUCKING INFORMATION FOR OLD-GROWTH DOUGLAS-FIR

PREFERRED BUCKING LENGTHS (FT) ARE:

OPTIMUM LOG LENGTH = 41
SECOND LOG LENGTH = 35
THIRD LOG LENGTH = 25
MINIMUM LOG LENGTH = 8
MINIMUM BUTT LOG = 17

MERCHANTABLE TOP DIAMETER (IN) = 6

MAXIMUM ALLOWABLE LOG WEIGHT (LB) = 15000

LOG LENGTH/WEIGHT TABLE FOR OLD-GROWTH DOUGLAS-FIR

		LOG NUMBER					
	TOTAL	1	2	3	4	5	6
DIAMETER CLASS==> 10							
(2 LOGS)							
LENGTHS=	51	40.9	9.7	0.0	0.0	0.0	0.0
EST WEIGHTS =	742	651	91	0	0	0	0
DIAMETER CLASS==> 20							
(2 LOGS)							
LENGTHS=	82	41.0	40.9	0.0	0.0	0.0	0.0
EST WEIGHTS =	3815	2671	1143	0	0	0	0
DIAMETER CLASS==> 30							
(3 LOGS)							
LENGTHS=	101	40.8	40.9	18.8	0.0	0.0	0.0
EST WEIGHTS =	9948	6204	3248	497	0	0	0
DIAMETER CLASS==> 40							
(5 LOGS)							
LENGTHS=	155	40.7	40.8	40.8	24.7	8.0	0.0
EST WEIGHTS =	26265	11994	7890	4968	1287	127	0
DIAMETER CLASS==> 50							
(5 LOGS)							
LENGTHS=	171	24.9	40.7	40.7	40.7	24.2	0.0
EST WEIGHTS =	44704	12919	14401	10468	5888	1027	0

Figure 6—Computer summary of the log weight table.

```
---------------------------SUMMARY TABLE FOR ALL LOGS---------------------------

                 ( *  INDICATES PAIR OF RIPPED LOGS)
                 ( ** INDICATES LOGS RIPPED TWICE STILL TOO HEAVY FOR YARDER)

DIAMETER LOG                                         SMALL-END
CLASS     NUMBER      LENGTH        WEIGHT      DIAMETER

 10
          1           40.9           651           6.8
          2            9.7            91           6.0
                                                       RESIDUE :
                       0.0             0   -  -  -  -(BOLE dia>m.t.)
                      34.5           129   -  -  -  -(BOLE dia<m.t.)
                                     221   -  -  -  -(     CROWN)

 20
          1           41.0          2671          14.2
          2           40.9          1143           6.0
                                                       RESIDUE :
                       0.0             0   -  -  -  -(BOLE dia>m.t.)
                      13.1            40   -  -  -  -(BOLE dia<m.t.)
                                     240   -  -  -  -(     CROWN)

 30
          1           40.8          6204          22.1
          2           40.9          3248          13.9
          3           18.8           497           6.1
                                                       RESIDUE :
                       0.0             0   -  -  -  -(BOLE dia>m.t.)
                       9.4            27   -  -  -  -(BOLE dia<m.t.)
                                     260   -  -  -  -(     CROWN)

 40
          1           40.7         11994          31.6
          2           40.8          7890          26.7
          3           40.8          4968          18.6
          4           24.7          1287          10.2
          5            8.0           127           6.0
                                                       RESIDUE :
                       0.0             0   -  -  -  -(BOLE dia>m.t.)
                      10.0            27   -  -  -  -(BOLE dia<m.t.)
                                     281   -  -  -  -(     CROWN)

 50
          1           24.9         12919          42.5
          2           40.7         14401          36.9
          3           40.7         10468          29.9
          4           40.7          5888          18.6
          5           24.2          1027           6.1
                                                       RESIDUE :
                       0.0             0   -  -  -  -(BOLE dia>m.t.)
                       8.7            23   -  -  -  -(BOLE dia<m.t.)
                                     305   -  -  -  -(     CROWN)
```

Figure 7—Computer summary with details of log lengths, weight, small-end diameters, and residue information.

Subroutine that calculates residue—The residue subroutine computes three weights: (1) the material that falls below the minimum merchantable length and has a diameter larger than the merchantable top (m.t.); (2) the material with a diameter smaller than the merchantable top; and (3) the continuous crown, which includes the branches and needles. The information is printed in the table as (bole dia. > m.t.), (bole dia. < m.t.), and (crown) (fig. 7). The crown model was developed by Snell and Max (1985) for old-growth Douglas-fir.

Model Validation

Data collected from the 18 sample trees were used to develop the coefficients for the prediction equations used in the program. The measurements taken from the 93 validation trees (DBHob, totht, and the lengths of the 326 logs) were entered into the program , and weights of the boles and logs were estimated. Estimated weights were compared with actual weights to determine a measure of bias and accuracy. Bias was calculated as the mean of the differences between the actual and the estimated weights for logs and boles. The accuracy was calculated as the mean of the absolute differences between the actual and the estimated weights.

Results and Discussion

Model Development

Parameter estimates from the regression analysis are provided in table 3. The conversion and taper equations (fig. 2) have high levels of significance (R^2) and low standard error of the estimates (SE). The green density equation, however, produced a rather low R^2 and a high SE (fig. 3). The green density equation is similar to those reported for old-growth Douglas-fir in southern Washington by Pong and others (1986). The variation in measured values around the function indicates that even within homogeneous old-growth stands moisture levels are highly variable among trees. The curvilinear form of the equation is characteristic, however, of most old-growth conifers and expresses high densities in the lowest portion of the bole, drop offs in density in the lower to middle portion, and gradual increases in density in the upper bole. The top portion of the bole was highly variable because of the greater proportion of sapwood (active transpiration) and the variable conditions of the crown (size and vigor) among the trees sampled.

Model Validation

Tables 4 and 5 provide the summary statistics comparing the estimated weights with the actual weights for the 93 validation trees (326 logs).

Table 4 summarizes the validation for logs located in various positions within the boles. Different bole positions demonstrated slightly varying accuracy levels with the butt logs having the lowest relative error (0.5 percent bias and 5.9 percent average error of the estimate) and the top logs the highest (2.8 percent bias and 10.5 percent average error of the estimate). If this model had been used for making decisions concerning load assembly in this stand (for aerial logging), loads containing numerous upper logs would have been susceptible to more overloads and underruns during aerial yarding because of greater error in estimates of log weights. Theoretically, loads containing the entire bole or loads with a variety of butt, middle, and top logs would tend to be more accurate in weight because of the canceling of positive and negative bias from the lower to upper portions of the bole. This is reflected in table 4 by the pooled bias of 0.1 percent.

Table 5 divides the validation trees into five diameter classes. The largest and smallest of the tree sizes were the least accurate. Small trees (less than 21 inches) were slightly underestimated (0.5 percent bias) but had a high average error of the estimate (12.9 percent) as compared to other classes. As the diameter class increases, the trend reverses with an increase in the overestimation (plus bias).

Table 3—Summary statistics for prediction equations

Dependent variable	Regression constants						Statistical measures 1/		
	a	b1	b2	b3	b4	b5	n	R^2	SE
DBHib	-0.19	.87					18	0.99	0.73
Rob	1.00	-1.88	7.00	-15.36	15.32	-6.09	18	.95	4.09
Rib	1.00	-1.45	5.44	-12.99	13.76	-5.75	18	.94	4.85
ds(ob)	2.12	1.04					18	.99	1.34
ds(ib)	1.17	1.06					18	.93	1.81
gden	47.71	-39.09	73.45	-39.65			18	.18	3.11

1/ DBHib=-a+b1(DBHob);

Rob,Rib=a-b1(relht)+b2(relht)^2-b3(relht)^3+b4(relht)^4-b5(relht)^5;

ds(ob),ds(ib)=a+b1(DBHob);

gden=a-b1(relht)+b2(relht)^2-b3(relht)^3; where:

DBHib = diameter at breast height inside bark;

DBHOb = diameter at breast height outside bark;

Rob = diameter ratio outside bark;

Rib = diameter ratio inside bark;

ds(ob) = diameter outside bark at the base of the bole;

ds(ib) = diameter inside bark at the base of the bole;

gden = the green density of the wood;

n = sample size;

R^2 = coefficient of determination; and

SE = standard error of the estimate.

Table 4—Actual log weights as recorded on scales compared to estimated log weights with data grouped by bole position

Bole position	Sample size	Mean actual weight 1/	Mean estimated weight 2/	Bias 3/		Mean absolute difference 4/		Root mean squared difference 5/	
		Pounds			Percent	Pounds	Percent	Pounds	Percent
Pooled 6/	326	2800	2836	+36.0	1.3	211.6	7.6	297.0	10.6
Butt	86	4499	4475	-24.4	.5	266.1	5.9	345.8	7.7
Second log	86	3378	3472	+93.9	2.8	271.3	8.0	367.5	10.9
Middle	84	1901	1945	+43.5	2.3	178.8	9.4	233.8	12.3
Top	68	1012	1040	+28.4	2.8	105.9	10.5	171.3	16.9

1/ Measured on truck scales.

2/ Estimated with the computer model.

3/ Bias is the mean of the differences between the actual and the estimated weights. The value is converted to a percentage by dividing the bias by the mean actual weight multiplied by 100.

4/ Accuracy measure: the mean of the absolute differences between the actual and the estimated weights. The value is converted to a percentage by dividing the mean absolute difference by the mean actual weight.

5/ Accuracy measure that will emphasize the error associated with large weights: the square root of the mean of the squared differences between the actual and estimated weights. The value is converted to a percentage by dividing the root mean squared difference by the mean actual weight.

6/ "Pooled" contains all logs within the bole; butt is the first log in the bole.

Table 5—Actual log weights as recorded on scales compared to estimated log weights with data grouped by diameter class

Tree diameter	Sample size	Mean actual weight 1/	Mean estimated weight 2/	Bias 3/		Mean absolute difference 4/		Root mean squared difference 5/	
		Pounds	Pounds	Pounds	Percent	Pounds	Percent	Pounds	Percent
Pooled 6/	326	2800	2836	+36.0	0.1	211.6	7.6	297.0	10.6
20.9	12	1485	1478	-7.4	.5	191.4	12.9	279.5	18.8
21-24.9	75	2228	2151	-77.7	3.5	168.4	7.6	218.0	9.8
25-28.9	108	2666	2650	-15.2	.6	208.7	7.8	300.8	11.3
29-32.9	106	3108	3209	+101.1	3.3	204.1	6.6	279.0	8.9
33	25	4414	4814	+344.0	7.8	395.2	9.0	498.0	11.3

1/ Measured on truck scales.

2/ Estimated with the computer model.

3/ Bias is the mean of the differences between the actual and the estimated weights. The value is converted to a percentage by dividing the bias by the mean actual weight multiplied by 100.

4/ Accuracy measure: the mean of the absolute differences between the actual and the estimated weights. The value is converted to a percentage by dividing the mean absolute difference by the mean actual weight.

5/ Accuracy measure that will emphasize the error associated with large weights: the square root of the mean of the squared differences between the actual and estimated weights. The value is converted to a percentage by dividing the root mean squared difference by the mean actual weight.

6/ "Pooled" contains all tree sizes. The other categories are diameter outside bark, 4-1/2 feet from the base of the tree.

Application

The Iterative Weight Program ITWGHT)[5/]

The iterative weight program (ITWGHT) program is available from the authors as an example of how we applied the iterative technique to help solve log production problems encountered in aerial logging operations. The program was designed for a specific application (log and residue weight tables), and the user may want to modify the language (for use on other computers) and structure of the program to meet other applications.

The iterative approach to estimating bole and log weights can aid the user in determining the potential merchantable and unmerchantable products available from the standing timber so that yarding operations can be evaluated before harvesting. The program is interactive, so the user has a multitude of options for data entries; for example, the program will accept standard inventory and harvesting information, such as DBH distributions, average height of the timber, various bucking lengths for log production, any merchantable top limit, and a target weight for the yarder.

ITWGHT is structured so that all iterative calculations are stored in arrays that can be passed to other programs. (Note: the user can save memory by eliminating the storage of arrays.) The program "Filer" is also available to aid the user in building files from inventory data and inserting new prediction equations into ITWGHT.

Developing Additional Prediction Equations and Operating ITWGHT

Collecting data for the program—An inventory (cruise) of the harvest unit is needed to develop stand characteristics, such as DBH distributions for each species, average tree heights for each diameter class, and the number of stems within each class. The user may wish to follow the inventory with a sampling of trees to build equations that are site specific for predicting diameters (taper equations) and green density rather than use the equations presented here. The sampling may require stratification of species, diameter classes, and locations within the harvest unit, if there is high variability within the stand. The variablity of the stand can be evaluated by the inventory data. A wide representation of diameter classes and the presence of more than two species will require the selection of a larger number of sample trees because of the need to build separate equations for each species and the requirement of sampling across the entire diameter range. Another indication of variation is the physical characteristics of the site. The presence of numerous exposures (aspects), the steepness and length of the slope, the appearance of depressions and dissections within the slope, and rock outcroppings are a few examples of physical site factors that can create strata within the stand where taper and green density will vary among trees of the same species.

The way in which the sampling rules are determined will be directly linked to the objectives of the user (the intended application of the model). For example, the user in cable logging systems may need to know what the heaviest logs in the unit will weigh or the maximum log length that can be bucked from the larger trees and still be yarded to the landing. The yarding system is often limited by the cable size and by the capacity of the yarder. In such cases, the sampling is directed toward the larger trees in the unit to maximize the accuracy within that size class. The actual precision and accuracy achieved by the model will also depend on the variability in the strata.

[5/]The iterative weight program (ITWGHT) was programmed in Hewlett-Packard's basic control language on a Hewlett-Packard 9845B microcomputer. The authors are currently working on an IBM PC version in BASIC and FORTRAN.

For applications covering the entire stand, such as in aerial logging, every tree has to be considered, and the sampling must draw from each species and diameter class. The user will need to balance the higher costs associated with a greater number of sample trees with the anticipated savings in logging efficiency (greater payloads with less aborts) because of more accurate estimates of load weight.

The site-specific diameter and green density data are then subjected to regression analysis, and new coefficients are inserted into the computer program. This step requires access to a statistical software package that includes polynomial regression.

How To Use the Results

The ITWGHT model allows preharvest evaluations of changes in various product mixes for a given timber resource (before the harvest) by changing the preferred log lengths and the target weight. For example, a target weight of 15,000 pounds may restrict the bucking of butt logs that are over 35 feet for trees with a DBH exceeding 50 inches, as shown in the log length/weight table (fig. 6). More aborts can be risked with a higher target weight because of the monetary value of the butt log in these large trees. Another option is to cut a short butt log or even an unmerchantable end and buck a longer second log. The yarding of whole boles for the smaller trees (up to 30 inches) can minimize log waste encountered in bucking operations taking place in the woods. Each bucking option can be analyzed before bucking instructions are presented to the crew. A crew's falling and bucking costs can be easily inserted into the model. The model allows the user to analyze actual stand data and to solve critical log production problems prior to any harvesting.

Conclusion

A computer model was developed that iteratively calculates the weight of the entire bole to any merchantable top and the weight of logs within the bole for old-growth Douglas-fir. The model provides accurate estimates of weight for logs as compared to the actual weights measured on scales. This approach to weight modeling appears to be an important tool for planning and evaluating logging operations. The potential for higher valued products can be increased during preharvest analysis with the model by allowing managers to provide accurate and detailed instructions to bucking crews. The flexible approach to estimating weight of logs and other tree components can result in cost savings by providing better estimates of payloads. Better estimates of payloads can lead to greater harvesting efficiency and increased safety.

Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.540	Centimeters
Feet	0.305	Meters
Cubic feet	0.028	Cubic meters
Pounds	0.454	Kilograms
Acres	0.405	Hectares
Pounds per cubic feet	16.019	Kilograms per cubic meter

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A computer model that estimates the green weights of standing trees was developed and validated for old-growth Douglas-fir. The model calculates the green weight for the entire bole, for the bole to any merchantable top, and for any log length within the bole. The model was validated by estimating the bias and accuracy of an independent subsample selected from the original stand. Calculated weights were compared to actual weights as measured on truck scales. The model accurately estimated the weight of logs (less than 10 percent error) and provides an estimation technique that is expected to have application for various elements of timber management.

Keywords: Models, weight scaling (log), log weights, computer programs/programing.

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